ADMI IJST International Journal Science and Technology

IJST Vol 2 No. 1 | March 2023 | ISSN: 2829-0437 (print), ISSN: 2829-050X (online), Page 65-72

PERFORMANCE ANALYSIS OF THE THERMOELECTRIC TEC 12706-BASED COOLING SYSTEM IN COOLER BOX DESIGN

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Article History
Received : Feb 2023
Revised : Mar 2023
Accepted : Mar 2023
Published : Mar 2023

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Cite This Article:
Abdul Muchlis, Kurnia Yogo Utomo, Supriyono, and Tri Mulyanto, "ANALYSIS OF THE PERFORMANCE OF THE THERMOELECTRIC TEC 12706-BASED COOLING SYSTEM IN COOLER BOX DESIGN", IJST, vol. 2, no. 1, pp. 65–72, Mar. 2023.

DOI:
https://doi.org/10.56127/ijst.v2i1.859

Abstract: The most widely used refrigeration machine today is a refrigeration machine that operates with a vapor compression cycle (SKU). To operate a vapor compression machine, refrigerant is needed as a working fluid. The most widely used refrigerants are chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. However, their use can damage the ozone layer and has a great potential to increase the effects of global warming. Therefore, a refrigeration system that is environmentally friendly and also has low power is needed, this can be fulfilled by using thermoelectric. This research was conducted to analyze the performance of temperature differences, heat absorbed, cooling capacity and COP in thermoelectric-based cooler boxes, thermoelectric performance with variations in input voltage and with variations in the addition of heatsinks where the method used is experimental by controlling the variable input voltage. From the research results, the calorific value absorbed is proportional to the increase in the applied voltage. Where the greater the voltage applied, the heat absorbed will be higher and the input power that enters the thermoelectric module is directly proportional to the incoming voltage where the greater the voltage. Then the power that goes into the thermoelectric will also be even greater. Whereas the COP value will decrease as the voltage increases and the best thermoelectric performance is with a voltage of 10 V. This can be seen after 60 minutes, the temperature difference value is 6.6 0K, the absorbed calorific value is 19,150 W, and the COP is 0.921. The thermoelectric performance is not only based on the COP value but also based on a review of the electric power consumed and the cooling speed during the 60 minute test. Then for the addition of a copper heatsink the COP value is 0.4832 and the temperature drop in the cooler box is only 3.9 0K, the value is lower than without the additional heatsink due to the gap between the aluminum heatsinks.

Keywords: Thermoelectric, Cooler Box, Heat Transfer

INTRODUCTION

Cooling is a process of absorbing heat from an object or room so that the temperature of the object or room drops lower than the surrounding temperature or environment [1]. The cooling system is a system that can lower and maintain the temperature of a room or certain materials to be lower in temperature than the ambient temperature. By transferring heat from the space or material to the outside of another system [5].

The most widely used refrigeration machine today is a refrigeration machine that operates with a vapor compression cycle. To operate a vapor compression machine, refrigerant is needed as a working fluid [3]. The most widely used refrigerants are chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants. However, its use can damage the ozone layer and has a great potential to increase the effects of global warming [4]. The medium used to transfer heat generally uses air and water. Currently the cooling system generally uses a vapor compression system where the necessary components are: compressor, condenser, expansion device, and evaporator.

However, over time, it is sufficient to replace it with one component in the form of a thermoelectric module using the Peltier effect which utilizes two different metals to be connected and then an electric current flows through the connection, a heat pump phenomenon will occur which will transfer heat from one side to the other. Thermoelectric are integrated circuits in solid form that use three thermodynamic principles known as the Seebeck, Peltier and Thompson effects. The thermoelectric construction consists of pairs of p-type and n-type semiconductor materials that form a thermocouple. This module can be used to generate heat and cold on each side if an electric current is used, usually applied as a cooling system. [8][9]. The working principle of thermoelectric coolers is based on the Peltier effect, that is, when a DC electric current passes through semiconductor materials of different types, semiconductor type N (negative) and type P (positive) will cause heat (heat released) on one side and cold (heat absorbed). on the other hand[10]. The thermoelectric effect is a reversible phenomenon that leads to direct conversion between thermal and electrical energy [11]. Meanwhile, the Peltier effect is a phenomenon when electrical energy is converted into heat energy [12]. And the Seebeck effect is a phenomenon when heat energy is converted into electrical energy, its application is usually used as a power plant, where the tool used is called a thermoelectric generator (TEG)[13][14].

Refrigeration is one of the most commonly used ways to preserve food. Storage of materials in low temperature rooms makes these materials not easily damaged because they can reduce enzymatic activity and chemical reactions by microbes [2]. Therefore we need a refrigeration system that is environmentally friendly and also has low power, this can be fulfilled by using thermoelectric which is a solid state technology that can be an alternative cooling technology to replace vapor compression systems.

The use of thermoelectric also does not require a lot of space to make it possible to make portable cooling machines, making it easier to use if they have to be moved from one place to another. Besides the advantages, thermoelectric has a drawback in the form of a fairly low efficiency. Therefore, the performance of this thermoelectric-based cooling system design will be analyzed, which is limited by the type of thermoelectric used, namely TEC 12706 which is installed in the cooler box design. In this study did not take into account the heat on the fan, power supply unit and step down converter. This design uses 2 parameter variations, namely input voltage variations and heatsink addition variations. Furthermore, the performance of the design is analyzed by looking at the difference in temperature, heat absorbed, cooling capacity and COP (Coefficient of Performance).

RESEARCH METHODS

The research method used in this paper uses experimental methods, where the implementation of experiments to be carried out in this study begins with problem identification and literature study, component preparation and setting. The design of the cooler box cooling system was tested to test whether it functions as expected or not. If there are errors or deficiencies, repairs or modifications are made.

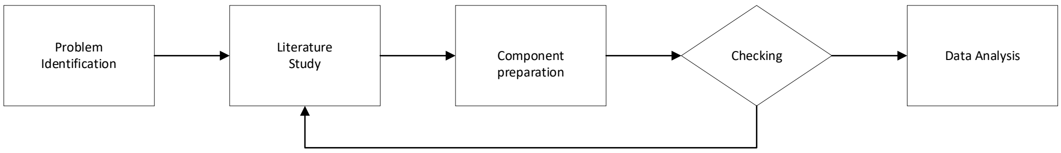

Figure 1. Flow analysis of the TEC 12706 thermoelectric performance on the cooler box

The current problem faced is the use of cooling media for food storage which still uses the ice cube method (wet ice) and vapor compression cooling systems. Furthermore, the identification of these problems is associated with a literature study by studying references from relevant journals and books, such as: the concept of heat transfer, heat loading, the Peltier effect on thermoelectric. Empirical studies are carried out by studying by estimating the need for cooling media, cooling load on the cooler box and also the use of thermoelectric. In this case it is done by studying related books and journals.

Thermoelectric TEC 12706

The thermoelectric used is a thermoelectric produced by Thermonamic with the code TEC1-12706 which has dimensions of 40x40x3.8 (mm) with a surface material of 96% aluminum oxide (Al2O3). The specifications of the thermoelectric used are as in the following table:

Table 1. Thermoelectric specifications (TEC)

Parameter	Value
Hot Side Temperature	25ºC – 50ºC
Delta Tmax (ºC)	66 – 75
Imax (Amps)	6.4
Vmax (Volts)	14.4 - 16.4
Module Resistance (Ohms)	1.98 – 2.30

W 1209 thermostats

The W1209 thermostat is a digital converter system that functions to convert temperatures, such as hot and cold, and activates heating or cooling until the temperature is reached at a certain degree.

DC Step Down Converter

A step down DC converter is an electronic circuit that functions as a DC to DC voltage step down (DC-to-DC converter or choppers), with the switching method. Broadly speaking, this dc-to-dc converter circuit uses switching components such as MOSFETs (metal oxide semiconductor field effect transistors), thyristors, IGBTs to regulate the duty cycle. In general, the components of a step down DC converter are a DC input source, control circuit (drive circuit), freewheeling diodes, inductors, capacitors, MOSFETs and loads. To produce a constant output voltage, the buck type DC chopper must be coupled with a feedback circuit as a comparison of the output value with the reference value. The difference between the output voltage of the circuit compared to the reference voltage will be used to produce an adjusted PWM duty cycle (auto adjust) to control the switching mosfet.

Power Supply Units

The function of the power supply is as hardware that provides or supplies an electric current that was previously changed from the form of an opposite electric current or AC, to a direct electric current or commonly referred to as a DC current. The power supply supplies the required DC electric current in the cooler box with a voltage of 12V and a current of 10 A.

Heatsinks

The heatsink is used to remove the means for releasing heat. The heatsink which is made of aluminum has dimensions of 90×90 mm with 20 fins and has a thermal conductivity value of 170 W/m.K. And for heatsinks made of cooper, they have dimensions of 40×40 mm with 10 fins.

Other Equipment

Cooler boxes are used with a capacity of 10 L, the material used is polyethylene as an outer and inner coating and polyurethane as insulation. This material was chosen because it has a good ability to maintain the temperature inside the tool and prevent the entry of heat from outside. The camera uses a cellphone with a resolution of 48 megapixels using an IMX 586 sensor. The cellphone camera is used to capture images on the voltmeter, thermometer and thermostat W 1209 at the same time with the help of an intervalometer application. Digital thermometer for measuring temperature or a tool used to indicate cold or hot degrees in the cooler box cooling system. Digital voltmeter to measure the amount of electric voltage in the cooler box electrical circuit system. The fan used is a fan with a one-way voltage source that has different sizes.

Component Settings and Testing

The following are the test installation component settings:

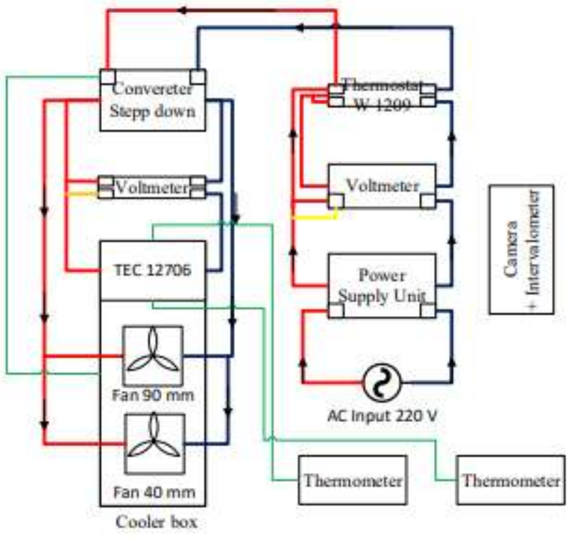

Figure 2. Setting of the test installation components

Data collection uses a cellphone camera with an intervalometer application which will take pictures every 5 minutes where the output is in the form of images that will be recorded manually. The data taken is the temperature of the hot side and the cold side of the thermoletric displayed by the thermometer and also the ambient temperature in the cooler box which is recorded on the thermostat. Retrieval of voltmeter and ampermeter data to measure input voltage and incoming current on thermoelectric. Testing thermoelectric performance by providing varying electric power at a voltage of 5 V, 7.5 V and 10 V. And testing thermoelectric performance by adding a cooper heatsink.

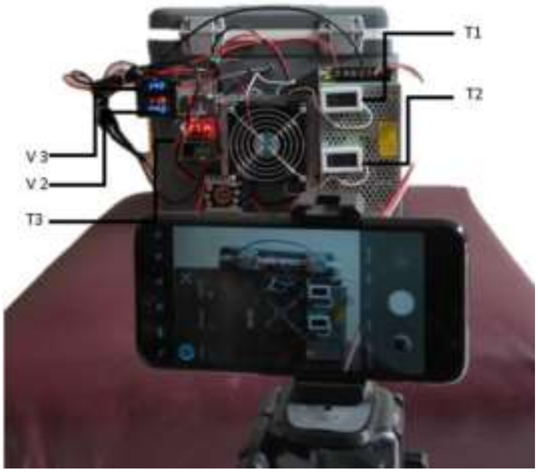

Figure 3. Data collection process

Information:

T1 : Temperature of the thermoelectric cold side
T2 : Thermoelectric hot cold temperature
T3 : Temperature cooler box
V2 : PSU output voltage
V3 : Thermoelectric input voltage

RESULT AND DISCUSSION

Thermoelectric performance with variations in input voltage, where the data will be presented in the form of a graph of the relationship between heat absorbed, input voltage and COP value. For the test points located on the hot side and the cold side of the thermoelectric can be seen in the test scheme where there is a thermometer to measure the temperature, and for the input voltage it can be seen on the voltmeter before entering the thermoelectric, for the temperature in the cooler box can be seen on the W1209 thermostat.

The working principle of this cooler box is that when the thermoelectric is given an input voltage it will cause a temperature difference on the cold side and the hot side. On the cold side, thermoelectric will absorb heat from the cooler box and throw it out on the hot side with the help of a heatsink and fan. The data collection process uses a cellphone camera with an intervalometer application which will take pictures every 5 minutes where the output is in the form of images that will be recorded manually. The data taken is the temperature of the hot side and the cold side of the thermoelectric displayed by the thermometer then the temperature in the cooler box on the W1209 thermostat and the input voltage on the thermoelectric displayed by the voltmeter.

Calculation of Heat Load

The data from the test results can be made into a heat load testing table (with a variation of voltage of 10V, 7.5V and 5V). There are differences in wall thickness in the cooler box design so that the total heat transfer coefficient in each field has a different value. The value of the total heat transfer coefficient in the cooler box includes:

1. The total heat transfer coefficient of the blanket area (Us)
2. The total heat transfer coefficient of the base area (Ua)
3. The total heat transfer coefficient of the closed area (Ut)

Based on the calculation of the total heat transfer coefficient for each field, the heat load through convection in each field is:

1. Heat transfer through the blanket (qs)

2. Heat transfer through the base plane (qa)
3. Heat transfer through the enclosure (qt)

To determine the value of the heat load through convection on the wall of the cooler box, the heat transfer equation is used:

$$q = U.A.\ \Delta T \quad (1)$$

1. Based on the calculation of heat transfer from each field, the total transfer rate can be known heat through convection cooler box wall of.
   qttotal = (0.0238 + 0.000529 + 0.000529) W = 0.02485W

2. Product load calculation, with product specifications as follows:
   Volume : 6x10-4 m3
   Density : 997 kg/m3
   Specific heat : 4181.6 J/kg.K
   Approx. : 302.5K
   Tcool : 295.9 K
   To find out the heat load of the product, you can use the equation:
   $$Qp = \rho.V.Cp.\ \Delta T/t \quad (2)$$
   $$Qp = \ 4.585 \text{ W}$$
3. Calculation of the infiltration heat load, with the general assumption of 15% of the total revenue load surface heat. (Ilyas, 1983)
   Qi = 15% × 0.02485 W = 0.0003727 W

4. Calculation of the total heat load, derived from the heat load through the walls of the cooler box, heat load product, and infiltration heat load.
   $Qtotal$ = 0.02485 W + 4.585 W + 0.0003727 W = 4.61 W

From the test results and calculation of the heat load through the cooler box with an input voltage of 10 V, 7.5 V and 5 V for 1 hour, a table can be compiled.

Table 1. Total heat load

Input Voltage	Total Heat Load
10 V	4.61 W
7,5 V	3.22 W
5 V	1.47 W
10 V (with *heatsink*)	2.09 W

Material Properties Thermoelectric Temperature Dependent
Maximum input voltage (Vmax) : 16 V
Maximum current (Imax) : 6.1 A
Maximum temperature difference (ΔT) : 70 K
Maximum hot side (Th) : 313.1 K

Calculation of Thermoelectric Performance

The following is a calculation of thermoelectric performance at an input voltage of 10V at 60 minutes:
Seebeck Coefficient (Sm) : 0.0511 V/K
Electrical Resistance (Rm) : 2.0365 Ω
Thermal Resistance (Θm) : 1.8474 K/W
Thermoelectric current (I) : 1.78 A
Thermoelectric hot side temperature (Th) : 312.05 K
Thermoelectric cold side temperature (Tc) : 282.92 K

a. Cooling Capacity (Qc) : Qc = 19.666 W

b. Heat Rejected (Qh) : Qh = 23.362 W
c. Electrical Power Input to Module (Pm) : Pm = 20.4702 W
d. Coefficient of Performance of The System (COP) : COP = 0.9607
The following table shows the difference in temperature in the cooler box within 60 minutes

Table 2. Temperature reduction with voltage variations for 60 minutes

Temperature	5 V	7,5 V	10 V	10 V (+ *heatsink*)
Room temperature (^{0}K)	302,5	302,5	302,5	302,5
Cooler box temperature (^{0}K)	300,4	297,9	295,9	299,6
Temperature difference (^{0}K)	2,1	4,6	6,6	3,9

So that a relationship can be made between the applied voltage to the calorific value absorbed by the cold side Qc, the electric power that enters the thermoelectric module, and the COP in graphical form.

1. The effect of the applied electric voltage on the heat absorbed by the cold side

Figure 4. Graph of the effect of the applied electric voltage on the heat absorbed by the cold side

From the graph it can be seen that the increase in the calorific value absorbed is affected by the increase in the electric voltage. For a 5V voltage, the Qc value is 5,750 W. For a 7.5V voltage, the Qc value is 11,881 W. For a 10 V voltage, the Qc value is 19,150 W. This shows that the increase in the calorific value absorbed is proportional to the increase in the applied voltage, where the greater the applied voltage, the higher the heat absorbed. This will make the temperature drop much higher, where the temperature drop at a voltage of 10 V is the highest, reaching 6.6 ^{0}K, at 7.5 V it is 4.6 ^{0}K and at a voltage of 5 V it is 2.1 ^{0}K. And with the addition of a heatsink at a voltage of 10 V the heat released is smaller than without the addition of a heatsink, the cold side can reach a lower temperature, reaching 3.1 ^{0}K, presumably because there is a small gap between the aluminum and copper heatsinks and not using thermal paste causing the cold side temperature to drop faster and the fan circulation inside doesn't work properly.

2. The effect of the applied voltage on the thermoelectric input power

Figure 5. Graph of the effect of the applied voltage on the thermoelectric input power

From the graph it can be seen that the increase in input power is directly proportional to the input voltage, where the greater the voltage, the greater the input power to the thermoelectric. For a voltage of 5 V the input power is 5,663 W, for a voltage of 7.5 V the power is 12,352 W and for a voltage of 10 V the power is 20,778 W. The voltage that enters the thermoelectric module is influenced by the incoming current which is at the highest current at a voltage of 10 V which is 2.88 A at a voltage of 7.5 V the current is 2.15 A and at a voltage of 5 V the current is 1.41 A. In addition, the amount of input power that goes into the thermo module electric is affected by the difference between the hot side and the cold side of the thermoelectric. In the addition of a copper heatsink with a voltage of 10 V the input power that goes into the thermoelectric is greater because the temperature difference between the hot and cold sides of the thermoelectric is greater, reaching 40.7 ^{0}K compared to without using an additional heatsink, which is 25.2 ^{0}K.

3. The effect of the applied voltage on COP

Figure 6. Graph of the effect of the applied voltage on COP

From the graph it can be seen that the COP value will decrease with increasing voltage. For a voltage of 5 V the COP is 1.019 V, for a voltage of 7.5 V the COP is 0.964 V and for a voltage of 10 V the COP is 0.921 V. The COP value depends on the heat absorbed on the cold side of the thermoelectric and the input power to the thermoelectric module. The highest COP value is at a voltage of 5 V, due to low power usage, it can be seen from the input power that enters the thermoelectric module and causes a temperature drop that is not too significant, because the heat absorbed is small. With the addition of a copper heatsink, the COP value is lower at the same voltage of 10 V because the calorific value released is lower, while the input power that goes into the thermoelectric module is greater. The COP value is a measure of the efficiency of a thermoelectric cooler which can be seen from the ratio of the amount of heat absorbed on the cold side (Qc) to the amount of incoming electrical power to the thermoelectric module (Pm). For now, thermoelectric coolers have a low COP value, so they cannot compete with vapor compression cooling systems.

Observations on the hot side, cold side, and temperature difference aim to see how the thermoelectric performance is when different voltages are applied. The higher the applied voltage, the hot side temperature will be higher and after 60 minutes of observation the hot side temperature is not constant, there are still increases and decreases. Likewise for the cold side temperatures. In accordance with the thermoelectric working principle based on the Peltier effect, heat is absorbed from the cold side of Qc and heat released to the environment is Qh. The difference between the two heats is the amount of electrical power needed.[7]

From the tests that have been carried out, the best thermoelectric performance is with a voltage of 10 V. This can be seen after 60 minutes the temperature difference is 6.6 K, the calorific value absorbed is 19,150 W , and the COP is 0.921. The thermoelectric performance is not only based on the COP value but also based on a review of the electric power consumed and the cooling speed during the 60 minute test.

CONCLUSION

Based on the results of an analysis of the performance of the cooling system based on the thermoelectric TEC 12706 in the cooler box, with variations in the input voltage, conclusions can be drawn:

The calorific value absorbed is proportional to the increase in the applied voltage, where the greater the applied voltage, the higher the absorbed heat. Then the input power that enters the thermoelectric module is directly proportional to the incoming voltage where the greater the voltage, the greater the incoming power to the thermoelectric. Meanwhile, the COP value will decrease as the voltage increases.

From the tests that have been carried out, the best thermoelectric performance with a voltage variation of 5V, 7.5V and 10V is at a voltage of 10V. The best thermoelectric performance with a voltage of 10V can be seen after 60 minutes, the temperature difference value is 6.6 0K, the absorbed heat value is 19,150 W, and the COP is 0.921. The thermoelectric performance is not only based on the COP value but also based on a review of the electric power consumed and the cooling speed during the 60 minute test.

Based on the results of the tests carried out, the use of an additional copper heatsink has a COP value of 0.4832 and the temperature drop in the cooler box is only 3.9 0K, the value is lower than without an additional heatsink due to the gap between the aluminum heatsinks.

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